Radiation and Health

JACOB I. FABRIKANT, MD, PhD, *Berkeley, California*

Professor Hendee discusses some of the important problems of patient exposure to medical x-rays, and he does it well.[1] But there are certain issues Professor Hendee's article addresses but does not clarify sufficiently to provide guidance on radiation and health for a busy practitioner of medicine. What is low-level radiation and why is it of concern? What are the radiation doses we are dealing with in diagnostic radiology and should these exposure levels be reduced? Is there potential harm from diagnostic radiation exposure? And is x-ray exposure during pregnancy dangerous to the developing embryo and fetus?

What Is Low-Level Radiation?

While there is no precise definition of low-level radiation, low-level exposure or low-dose radiation, scientists generally agree that low-level radiation is that which falls within the dose range considered permissible for occupational exposure. According to the accepted standards of the International Commission on Radiological Protection (ICRP), 5 rems (0.05 sievert [Sv]) per year to the whole body would be an allowable upper limit of low-level radiation dose for the individual radiation worker.[2] In this context it could be concluded that prolonged exposure to these levels of diagnostic radiation or prolonged periods of occupational exposure among radiation workers are considered by some scientists to cause delayed radiation health effects, such as cancer or hereditary defects. Other scientists strongly dispute this and firmly believe that low-level radiation is nowhere nearly as dangerous as their colleagues would contend.[3] The issue is a difficult scientific one because such health effects, if any do occur, are so rarely seen from low-level radiation because the exposures are so small. The issue of this scientific dispute may never be resolved—it may be beyond the abilities of science and mathematics to decipher.[4]

What Are Some of the Radiation Doses From Common X-ray Procedures?

The radiation doses from x-ray examinations are limited to defined regions of the body; the radiant energy absorbed by the tissues is generally much the same wherever the procedure is done in the United States.[5] For a chest x-ray study, the dose to the bone marrow in the thorax—the important target tissue—is about 10 to 20 mrads (0.1 to 0.2 milligray)* per projection. For the hip and upper femur, the dose is about 75 mrads (0.75 mGy). And for dental radiography, a complete mouth examination may involve 10 mrads (0.1 mGy) to the bone marrow. Mammography today ranges about 1 to 5 rads (0.01 to 0.05 Gy), but new techniques permit this to be reduced to only 0.5 rad to the breast per study. A barium enema is a "high-dose" examination—the average is close to 1 rad (0.01 Gy), but it could be as high as 3 rads (0.03 Gy). Special radiologic procedures, such as angiography of the abdomen, may be as low as 400 mrads (4 mGy), but can be much higher. Computerized tomography (CT) scans of the brain may involve a dose as high as 4 rads to the portion of the brain exposed; but the new CT units have decreased this to a range of about 1 rad or 0.01 Gy. X-ray pelvimetry to the pregnant mother ranges from 600 mrads (6 mGy) to about 1 rad (0.01 Gy); the fetus receives a dose of about half this amount.

Are the Epidemiologic Studies on Radiation Carcinogenesis in Human Populations Valid?

The epidemiologic evidence is compelling—cancer arising in a variety of organs and tissues and transmitted genetic effects are the principal late effects in populations of exposure to low levels of ionizing radiation.[2,3,6-8] Since the late 1940s and early 1950s, it has been postulated that there may be no threshold level of exposure to ionizing radiation below which risks of injury are entirely lacking. At the same time, however, it has been recognized that the risks of exposure at levels of natural background can be estimated only by interpolation between levels of health effects observed at high doses and

*In the new system of international units, 1 Gy (gray) = 100 rads, and 1 Sv = 100 rems.

Refer to: Fabrikant JI: Radiation and health (Editorial Comment). West J Med 1983 Mar; 138:387-390.
Dr Fabrikant is Adjunct Professor of Radiology, University of California, San Francisco, School of Medicine, and Donner Laboratory, University of California, Berkeley.
Research supported by the Director, Office of Energy Research, Office of Health and Environmental Research of the US Department of Energy under contract No. DE-AC03-76SF00098.
Reprint requests to Jacob I. Fabrikant, MD, PhD, Donner Laboratory, University of California, Berkeley, CA 94720.

dose rates and spontaneous levels of the same effect. The assumption of a linear, no-threshold dose-response relationship (linear hypothesis) has generally been considered to provide a conservative approach to risk estimation for low-dose and low-dose-rate exposure, because the effect per unit dose for low-linear energy transfer (LET) radiations (for example, x-rays and γ-rays) has usually been observed in biology and medicine to decrease with decreasing dose and dose rate.[7]

Several reports have been published, some recently, that seem to indicate degrees of carcinogenic radiation effects at low doses in humans that would be incompatible with a conservative linear hypothesis. This would lead to claims that low-level exposure, in fact, may be more hazardous per unit of absorbed dose than at high doses and dose rates. These data and claims, therefore, suggest that this dose-response relationship at low doses does not lead to conservatism, but may even underestimate the effects of low doses and low dose rates. However, each of these epidemiologic studies provides information that has been heavily criticized for serious statistical and methodologic difficulties and, individually or collectively, are not scientifically convincing enough to argue against either the conservatism of the linear hypothesis or the present estimate of risk of cancer induction in human populations exposed to low levels of ionizing radiation.[3,7] They stand apart from, and in disagreement with, the large body of epidemiologic evidence that convincingly shows the carcinogenic and hereditary effects in humans after exposure to low doses and low dose rates.

Are There Any Contraindications to Diagnostic X-ray Examinations?

There are no contraindications to any medical examination; rather, there are indications for a clinical examination. X-ray procedures, however, have an unwanted by-product that is of no benefit to the patient, namely, ionizing radiation that is absorbed by the cells and tissues of the body. A good rule, therefore, is never to expose a patient to unnecessary radiation, and to expose the patient only to that amount of radiation which provides the diagnostic radiologic information.

There are, however, special circumstances to consider because there is a benefit to be gained for a patient's health, and this is invariably associated with the risk of radiation injury resulting in an increased probability of delayed or late health effects occurring in that patient. Probability is the mathematical chance of something occurring; risk is when that probability is associated with a detriment, such as ill health. When the benefit strongly outweighs the risk, then we are not as concerned—as, for example, radiation exposures attendant in specialized procedures, such as examination of the coronary arteries in a patient with cardiovascular disease, or computerized tomography of the brain in a patient with a possible cerebral hemorrhage. In these cases, the benefit-to-risk ratio is high.

But there are occasions when the benefit to the patient of a diagnostic radiologic procedure is small or even negligible, and the attendant risk of radiation exposure, though equally small, may become relatively high; that is, the benefit-to-risk ratio is low or the risk may be even greater than the potential benefit. The best examples here are the mass screening x-ray studies, for example, chest photofluorography for tuberculosis or lung cancer in asymptomatic populations and screening mammography in women with extremely low breast cancer risk, such as women younger than 35 years of age who do not have breast cancer risk factors. That is why the American College of Radiology recommends that such mass x-ray screening programs of asymptomatic populations that result in low diagnostic yields not be undertaken.

Is There Potential Harm From Diagnostic Radiation Exposure?

There is always the potential for harm from exposure to ionizing radiation such as x-rays. Ionizing radiation has several injurious effects, such as cataracts of the lens of the eye and impaired fertility, but three late or delayed health effects stand out as those of greatest concern—carcinogenesis, or cancer induction; teratogenesis, or developmental abnormality of the newborn; and mutagenesis, or genetically related ill health occurring in descendants of exposed persons.[9] Scientists now believe that exposure to ionizing radiation—because of the structure and function of the important living molecules, the DNA molecules within the cell and the manner in which energy is deposited in the molecular structure —increases the probability of such deleterious health effects. Further, as the dose of radiation increases above low levels, the risk of these deleterious effects increases in exposed human populations. However, these events at the biophysical level of the cell are extremely rare, due primarily to the efficiency of repair of radiation injury.[7] Even when injurious radiation effects occur, resulting in a lesion in the DNA molecular structure, the cells and tissues have an enormous capacity to repair the radiation damage, so that no residual injury remains.[7] Because such health effects, if any, are so rarely seen from low-level radiation, and because the health effects induced by radiation are indistinguishable from those occurring naturally, it follows that their existence can be inferred only on the basis of a statistical excess above the natural incidence in exposed populations.[3] Thus, at the dose levels of diagnostic radiologic exposure normally encountered in radiologic procedures in the United States, it follows that there is only a very slight probability of increased deleterious health effects resulting from diagnostic radiation exposure of about 100 million Americans each year.

Is X-ray Exposure During Pregnancy Especially Dangerous?

If there are indications for examination of the fetus or pelvis, where pelvimetry or obstetric abdominal examination will provide the diagnostic information, then x-ray studies can be carried out safely.[10] Circumstances exist, however, in which a series of x-ray studies are done for diagnosing ill health in the mother and, on occasion, there is no knowledge that a pregnancy exists. Each situation is then weighed according to the benefits and risks, inevitably the risks to a fetus. There are two delayed health effects of concern. The first is developmental abnormality in the newborn resulting from radiation teratogenesis during the first trimester when the fetus is unusually susceptible to radiation injury.[8] Here, teratogenesis is strongly dependent on the stage of gestation at which exposure occurs. Evidence from the Japanese atomic bomb survivors suggests decreased head size associated with mental retardation has occurred from exposure in utero to dose levels below 10 rads (0.1 Gy).[3] The second delayed health effect is cancer induction, notably leukemia, resulting from x-ray doses in the range of 1 to 2 rads (0.01 to 0.02 Gy) following exposure in utero during the last trimester.[3] One study strongly suggests this conclusion, with another ten or so tending to support the findings of this study.[11] Evidence is mounting, however, that indicates too many biases in the one positive study and, in fact, certain of the findings on childhood cancers may prove to be spurious.[12] The controversy is not settled, but the introduction of ultrasound pelvimetry as the primary method of examining the fetus and the pregnant abdomen is making the conclusion of the controversial study somewhat academic.

The "ten-day rule" is a recommendation that x-ray examination of a woman's abdomen be done only during the ten-day interval between the onset of the patient's menstrual period and the tenth day thereafter. It is based on the assumption that a woman cannot be pregnant during that interval. This "rule" is only a suggestion to decrease the probability of unsuspectingly exposing a developing embryo or fetus. The idea has been popular in some medical centers in Great Britain but not in the United States, though it has been recommended in clinical radiology.

The evidence that radiation exposures at levels of diagnostic radiology can induce cancer in the developing fetus, particularly the findings among the atomic bomb survivors,[13] remains somewhat controversial. There are a number of arguments for and against the conclusion that such low doses are carcinogenic in a fetus. However, there has been some reticence to accept a ten-day rule in clinical practice. Some radiologists have argued that such a requirement would disrupt patient scheduling in a large, busy x-ray department. Others have argued that ten days is not precise—it may be necessary to cover a 14-day period, because ovulation occurs in most women during a 14-day interval. Perhaps the most compelling argument against deferring an x-ray study of the abdomen for a period until menstruation occurs is that the condition that warranted the examination may no longer exist. It is good practice not to expose a pregnant uterus to x-rays unknowingly or unnecessarily—but if a patient is acutely ill, the benefits of the study may far outweigh the very small potential risk to an embryo.

What Can We Conclude?

In the evaluation of epidemiologic surveys and findings in laboratory animals, national and international advisory committees on radiation and health carefully review and assess the available scientific evidence for estimating the risks of the health effects in human populations exposed to low-level radiation.[4-9] The present scientific evidence and the interpretation of available epidemiologic data can draw those necessary conclusions on which to base scientific public health policy for radiation protection standards.[14] Based on the radiation risk estimates derived, any lack of precision minimizes neither the need for setting responsible public health policies nor the conclusion that such risks are extremely small when compared with available alternative options and risks normally accepted by society as the hazards of everyday life. When compared with the benefits that society has established as goals derived from the necessary activities of medical care, it is apparent that society must establish appropriate standards and seek appropriate controlling procedures that continue to assure that its health needs and services are being met with the lowest possible risks.

After a third of a century of inquiry, embodying among the most extensive and comprehensive scientific efforts on the health effects of any environmental agent, much of the important information necessary for determination of radiation protection standards is now available to decision makers for practical and responsible public health policy. It is now assumed that any exposure to radiation at low levels of dose carries some risk of deleterious health effects. However, how low this level may be, or the probability or magnitude of the risk at very low levels of dose, still are factors that are unknown and may remain so. Radiation and the public health, when it involves the public health, becomes a broad societal problem and not solely a scientific one, and to be decided by society, most often by men and women of law and government. Our best scientific knowledge and advice are essential for the protection of the public health and for the effective application of new technologies in medicine. Unless we wish to dispense with those activities that inevitably involve exposure to low levels of ionizing radiations in medicine, we must recognize that some degree of risk to health, however small, exists.

REFERENCES

1. Hendee WR: Real and perceived risks of medical radiation exposure (Medical Progress). West J Med 1983 Mar; 138:380-386.

2. International Commission on Radiological Protection: Recommendations of the International Commission on Radiological Protection, ICRP publication 26. Oxford, Pergamon Press, 1977

3. National Research Council's Advisory Committee on the Biological Effects of Ionizing Radiation: The Effects on Populations of Exposure to Low Levels of Ionizing Radiation. Washington, DC, National Academy Press, 1980

4. Fabrikant JI: Epidemiological studies on radiation carcinogenesis in human populations following acute exposure: Nuclear explosions and medical radiation. Yale J Biol Med 1981; 54:457-469

5. Klement AW, Miller CR, Minx RP, et al: Estimate of ionizing radiation doses in the US 1960-2000. US Environmental Protection Agency, ORP/CSD 72-1, 1972

6. National Council on Radiation Protection and Measurements: Review of the Current State of Radiation Protection Philosophy, NCRP report No. 43. Government Printing Office, 1980

7. National Council on Radiation Protection and Measurements: Influence of Dose and Its Distribution in Time on Dose-Response Relationships for Low-LET Radiations, NCRP report No. 64. Government Printing Office, 1975

8. United Nations' Scientific Committee on the Effects of Atomic Radiation: Sources and Effects of Ionizing Radiation. New York, United Nations, 1977

9. Fabrikant JI: The BEIR-III Report: Origin of the controversy. AJR 1981 Jan; 136:209-214

10. The Selection of Patients for X-ray Examinations: The Pelvimetry Examination, US Dept of Health and Human Services publication (FDA) 80-8128. Rockville, Md, PHS, FDA, BRH, Jul 1980

11. Kneale GW, Stewart AM: Mantel-Haenszel analysis of Oxford data—1. Independent effects of several birth factors including fetal irradiation. J Natl Cancer Inst 1976; 56:879-883

12. Boice JD Jr, Land CE: Ionizing radiation, chap 3, *In* Schottenfeld D, Fraumeni JF Jr (Eds): Cancer Epidemiology and Prevention. Philadelphia, WB Saunders, 1982, pp 231-253

13. Beebe GW: The atomic bomb survivors and the problem of low-dose radiation effects. Am J Epidemiol 1981; 114:761-783

14. National Research Council: Federal Research on the Biological and Health Effects of Ionizing Radiation. Washington, DC, National Academy Press, 1981